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13 May 2003

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SUBJECT: Contract F41624-97-D-8006
MMR Plume Response Program
DO 0006 DCN/PROJECT # ENR-J23-35Z15616-M31-0003
Final Fuel Spill-1 2002 Annual System Performance and Ecological Impact Monitoring Report, May 2003

Dear Mr. Gill:

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Sincerely,

Lauren Foster for
Michael J. Goydas
Program Manager

MJG/ctg

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Massachusetts Military Reservation

PLUME RESPONSE PROGRAM

Final Fuel Spill-1 2002 Annual System Performance and Ecological Impact Monitoring Report

May 2003

Prepared for:
AFCEE/MMR
Installation Restoration Program
322 E. Inner Road
Otis ANGB, MA 02542

Prepared by:
Jacobs Engineering Group Inc.

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ACRONYMS AND ABBREVIATIONS

AFCEE	Air Force Center for Environmental Excellence
BOD	biological oxygen demand
°C	degrees Celsius
cfs	cubic feet per second
CMR	Commonwealth of Massachusetts Regulations
COD	chemical oxygen demand
DEP	Massachusetts Department of Environmental Protection
DO	dissolved oxygen
EDB	ethylene dibromide (1,2-dibromoethane)
EPA	U.S. Environmental Protection Agency
ft bgs	feet below ground surface
ft/day	feet per day
ft msl	feet mean sea level
FS-1	Fuel Spill-1
GAC	granular activated carbon
gpm	gallons per minute
J	estimated value
kg	kilograms
lbs	pounds
MCL	EPA (drinking water) maximum contaminant level
mg/L	milligrams per liter

ACRONYMS AND ABBREVIATIONS

MMCL	Massachusetts (drinking water) maximum contaminant level
MMR	Massachusetts Military Reservation
MPP	Mashpee Pitted Plain
mV	millivolts
NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity units
ORP	oxidation-reduction potential
pH	hydrogen ion activity (representation of acidity or alkalinity)
QPP	*Quality Program Plan*
RBC	risk-based concentration
SMCL	secondary maximum contaminant level
SPEIM	system performance and ecological impact monitoring
SWP	shallow wellpoint
VOC	volatile organic compound
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter

EXECUTIVE SUMMARY

This *Final Fuel Spill-1 2001 Annual System Performance and Ecological Impact Monitoring Report* presents the results of monitoring conducted from May 2001 through April 2002 for the Fuel Spill-1 (FS-1) plume and remedial system. In addition to reporting monitoring results for the reporting period, this annual report provides an assessment of the FS-1 remedial system performance based on the past year of operation and monitoring.

The FS-1 remedial system captures ethylene dibromide (EDB) near the leading edge of the FS-1 contaminant plume. The system is currently composed of one deep extraction well (pumping 300 gallons per minute [gpm]), 175 shallow extraction wellpoints (103 are in operation with a cumulative pumping rate of 450 gpm), and an activated-carbon filtration system. The system discharges treated water to an infiltration trench (120 gpm) and through a riser pipe (bubbler) to the Quashnet River (630 gpm). Between May 2001 and April 2002, the remedial system removed 0.99 kilograms (kg) (2.2 pounds [lbs]) of EDB from 384 million gallons of contaminated groundwater. Since April 1999, the remedial system has removed 4.35 kg (9.6 lbs) from approximately 1.05 billion gallons of contaminated groundwater.

Monitoring was conducted to evaluate (1) the chemical and physicochemical characteristics of groundwater before and after treatment, (2) the FS-1 plume both upgradient and in the vicinity of the Quashnet River and bogs, and (3) surface water both upgradient and downgradient of the treatment discharge points. Stream gauging was also conducted to determine where groundwater was upwelling to the Quashnet River and bogs complex. Treatment plant operations were also monitored to assess the mass of EDB removed from extracted groundwater.

Surface water monitoring data suggest several positive effects due to the remedial system operation: (1) there were no EDB detections in the surface water of the K1 or K2 bogs ditches; (2) discharge of treated groundwater moderated the seasonal temperature fluctuations of the surface water in the upper reach of the K2 bog west ditch;

(3) discharge of treated groundwater through the bubbler increased surface water dissolved oxygen concentrations in the upper reach of the K2 bog west ditch; and (4) discharge of treated groundwater increased the flow in the K2 bog west ditch and the K1 bog ditch, which aids in the removal of fine-grained material from the sediments, exposing the coarser sand and gravel needed for brook trout spawning.

Monitoring of surface water, both upgradient and downgradient of the remedial system discharge points, indicates that, with the exception of periodic localized temperature exceedances during December 2001 through March 2002 and periodic small pH exceedances, the system was in compliance with the Commonwealth of Massachusetts Surface Water Quality Standards in 314 CMR 4.00.

Preliminary risk screening[1] for surface water entailed the comparison of EDB concentrations to the calculated human health risk-based concentration (RBC) for a risk of 10^{-3} and published ecological benchmarks. The highest EDB concentration measured in surface water was 0.190 micrograms per liter (µg/L), which was less than the RBC (6.5 µg/L) and the ecological benchmark (31 µg/L).

EDB concentrations in groundwater were found to exceed Massachusetts maximum contaminant level (MMCL) standards for drinking water (0.02 µg/L) in 50 of 99 groundwater monitoring well, piezometer, and shallow extraction well locations within the mapped footprint of the plume. The concentrations of volatile organic compounds (VOCs) and metals detected in the groundwater of the source area were below their respective maximum contaminant level (MCL) or MMCL.

EDB has never been detected in FS-1 treatment plant effluent samples. Therefore the remedial system successfully removed EDB from extracted contaminated groundwater.

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[1] The human health risk screening was conducted to provide a preliminary indication of imminent risk to human health and is not intended to supersede the risk assessment in the remedial investigation.

EDB concentrations have declined at most locations throughout the plume (and therefore contaminant mass has declined), but the overall plume geometry remains essentially unchanged from the previous depictions (AFCEE 2002c, 2001a, 2000a). This indicates that the remedial system has removed a significant portion of the FS-1 plume mass. However, EDB-contaminated groundwater continues to upwell in the K6 bog. The periphery of the plume (specifically the eastern edge) is not captured by the deep extraction well, indicated by increasing EDB concentrations in downgradient monitoring wells.

Monitoring of the FS-1 source area identified five compounds associated with petroleum products (ethylbenzene, toluene, ortho- and meta- plus para-xylene) and one metal (lead). For the VOCs, the low concentrations of these constituents and declining trends in concentrations indicate that there is no continuing source for the FS-1 plume and that natural attenuation will soon remove these compounds entirely. Lead will also be removed from groundwater by precipitation or adsorption as the geochemical environment reverts to background conditions. These compounds do not appear to be migrating because they have not been detected in the nearest downgradient well.

On 13 October 2002, the FS-1 treatment plant was destroyed by a fire. The FS-1 treatment system has been inoperative since that time. A focused monitoring effort was approved, was implemented beginning October 2002, and will continue until a new plant is operational. Details of the current monitoring of the FS-1 plume are presented in project note ENR-J23-35Z15616-P1-0004, Changes to the FS-1 SPEIM Program, dated 31 January 2003.

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1.0 INTRODUCTION

This *Final Fuel Spill-1 2002 Annual System Performance and Ecological Impact Monitoring Report* has been prepared as part of the Air Force Center for Environmental Excellence (AFCEE) Installation Restoration Program at the Massachusetts Military Reservation (MMR) on Cape Cod, Massachusetts under Remedial Action Contract No. F41624-01-D-8547, Task Orders 0006 (system performance and ecological impact monitoring [SPEIM]) and 0007 (treatment system monitoring). This assessment report meets Task Order 0006 requirements for an annual SPEIM assessment. The report evaluates monitoring data collected from May 2001 through April 2002. The location of the Fuel Spill-1 (FS-1) plume is illustrated in Figure 1-1.

The FS-1 remedial system is designed to intercept contaminated groundwater by extracting deep groundwater with one deep extraction well and shallow groundwater with an array of shallow extraction wellpoints. The shallow wellpoint (SWP) extraction system is designed to intercept upwelling groundwater before it discharges to the Quashnet River or cranberry bog ditches.

The primary objectives of the FS-1 SPEIM program are to assess (1) the performance of the treatment system, (2) human health risks associated with the FS-1 plume, and (3) potential ecological impacts associated with the operation of the remedial system. Secondary objectives of the SPEIM program are to assess (1) potential operation efficiency gains and (2) the appropriateness of the monitoring network.

Data collected under the FS-1 SPEIM program included ethylene dibromide (EDB) concentrations and water quality parameters in groundwater and surface water; volatile organic compounds (VOCs) and metals in groundwater in the source area of the FS-1 plume; and groundwater elevation and stream gauging measurements. EDB concentrations were also monitored in selected shallow wellpoints to aid in the evaluation of remedial system performance and plume upwelling characteristics, and to optimize the remedial system. The treatment system influent and effluent streams were monitored for EDB and water quality parameters to assess EDB removal and to guide treatment plant

operations. The effluent stream was also monitored for physicochemical parameters to assess potential changes in the chemistry of the groundwater during treatment. The flow rate of the deep extraction well and SWP system were monitored to estimate the volume of contaminated groundwater treated and EDB mass removed by the FS-1 remedial system during the reporting period.

AFCEE conducted a baseline survey of a sphagnum wetland, potentially impacted by the proposed expansion of the FS-1 treatment system described in the *Final Fuel Spill-1 Wellfield Design Report* (AFCEE 2001a). The wetland survey was performed at the request of the town of Mashpee as specified in the town of Mashpee's Amended Order of Condition for the construction of the expansion of the FS-1 extraction system. Although the wetland survey was conducted during the spring and summer of 2002 (outside the reporting period presented in this report), it has been included in this report.

This annual report is organized into six sections and contains five appendixes. Section 1.0 is the introduction for this report. Section 2.0 provides background information on the FS-1 plume and a description of the FS-1 remedial system. Section 3.0 describes the monitoring activities performed during the reporting period (May 2001 through April 2002). Section 4.0 discusses the results of the monitoring activities (i.e., hydraulic, groundwater chemistry, surface water chemistry, and remedial system monitoring). Section 5.0 presents the summary conclusions and recommendations based on the monitoring and treatment plant operations data collected during the reporting period. Section 6.0 contains the references cited in this report.

Analytical data for the third and fourth quarters of the reporting period are discussed in Appendix A and presented in Appendix B. Appendix C presents the preliminary screening-level human health risk evaluation for FS-1 surface water and treatment system effluent data. Appendix D presents the sphagnum bog ecological baseline survey completed during the spring and summer of 2002.

2.0 BACKGROUND

This section summarizes the history of the FS-1 plume relative to the occurrence of EDB contamination of groundwater and surface water of the upper Quashnet River and associated cranberry bog complex, and contains updated descriptions of the ecological and hydrologic conceptual site models and the treatment system.

2.1 HISTORY OF THE FS-1 PLUME

The FS-1 source area resulted from the testing of aircraft fuel dump valves by the 551st Airborne Early Warning and Control Wing between 1950 and 1970. The valves were opened and aircraft fuel was allowed to drain onto the concrete surface. The exact quantity of fuel released is unknown. EDB was an aviation fuel additive that has migrated southward in groundwater toward the Quashnet River (AFCEE 1999c). The hydrocarbon fraction of the fuel constituents underwent relatively rapid biodegradation and is no longer present in significant quantities in the source area. EDB is the only contaminant of concern in the FS-1 plume. EDB has migrated south of the source area because it is more soluble in water and not as readily biodegraded compared to other fuel constituents.

EDB was initially detected in the Quashnet River and bogs in August 1997 (HAZWRAP 1998). Since then, it has been determined that EDB contamination has impacted the surface water quality of approximately 28 acres of developed cranberry bogs just east of Johns Pond (AFCEE 1999c). The developed bogs are divided into six units designated K1 through K6. The largest are the K2 and K6 bogs, and the smallest is the K1 bog (Figure 2-1).

The estimated volume of contaminated water contained in the plume, as of October 2000, is 1.52 billion gallons, including 8.1 kilograms (kg) (17.1 pounds [lbs]) of EDB (AFCEE 2001a). The FS-1 plume is approximately 6525 feet long, 560 to 1200 feet wide, and 35 to 180 feet thick (AFCEE 2001a).

2.2 SITE CONCEPTUAL MODELS

The ecological and hydrologic conceptual models were developed to aid in visualizing the interactions of the Quashnet River and bogs system, groundwater, and the treatment system. Schematic depiction of the hydrologic conceptual model is presented in Figure 2-2.

2.2.1 Ecological Conceptual Model

The upper Quashnet River and bogs area is habitat for a large variety of animals (e.g., birds, fish, amphibians). The ecosystems in the study area derive their water from the Quashnet River (Johns Pond and the northern tributary of the Quashnet River), upwelling groundwater, and the treatment system. Treated groundwater is discharged to the K1 bog through an infiltration trench along the northwest bog ditch and to the K2 bog west ditch through a bubbler. The bubbler is a vertical corrugated steel pipe that allows the treated water to cascade over its sides. The cascading action aerates the treated water.

The flow of the Quashnet River is manipulated by a series of weirs that have been constructed for cranberry growing operations and to provide migrating herring access to their spawning grounds in Johns Pond. As a result, water levels in this area are regularly altered by cranberry cultivation operations and other controls used to encourage or discourage fish migration. Agricultural activities (i.e., cranberry growing activities) have greatly impacted the ecology of the area by limiting the variety of wetland vegetation types and maintaining an environment optimal for cranberry growth. In some cases, the agricultural activity has enhanced water quality and fish habitat by clearing sediment from the bog ditches and exposing gravel needed for brook trout spawning.

2.2.2 Selected Physical, Chemical, and Biological Properties of EDB

EDB is the only chemical of concern in the FS-1 plume. The primary uses for EDB were as an anti-knock agent in gasoline and as a fumigant. EDB has the following physical and chemical properties: (1) slightly soluble in water (4.3 milligrams per liter [mg/L]), (2) moderately volatile (vapor pressure of 11 millimeters of mercury and Henry's Law

constant of 3.16 x 10^{-4} atmospheres cubic meters per mole), and (3) octonal-water partition coefficient of 1.82 (AFCEE 1998).

The vapor pressure and Henry's Law constant indicate EDB will readily partition from surface water and surface soils to the atmosphere. The low octonal-water partition coefficient suggests that EDB will leach from contaminated soil to surface water and/or groundwater.

Chemical degradation rates for EDB (hydrolyzation) are relatively slow (the EDB hydrolyzation half-life has been estimated at 2.5 to 13 years) (AFCEE 1998). EDB does biodegrade under aerobic conditions, but the biodegradation rate is limited under anaerobic conditions. Because biodegradation of fuel spill constituents create anaerobic conditions, EDB would be expected to persist in the groundwater (AFCEE 1998). Because the FS-1 plume is detached from the source area and the groundwater contained within the plume is generally oxic, aerobic biodegradation is likely attenuating the EDB concentrations in the FS-1 plume. Monitoring data have confirmed that the EDB spilled in the FS-1 source area has either volatilized to the atmosphere or leached to the groundwater and moved south of the base boundary. Additionally, monitoring data have confirmed that once the EDB-contaminated groundwater upwells to the surface waters of the bogs, it volatilizes to the atmosphere.

There is concern that the upwelling of EDB-contaminated groundwater in the cranberry bog ditches may affect the health of the organisms that inhabit this area. The EDB exposure routes for organisms is through inhalation, absorption, or ingestion. Because EDB has a low bioaccumulation factor (10), it does not concentrate in organisms through the food chain (AFCEE 1998). As EDB-contaminated groundwater upwells to the surface water of the bog ditches, the EDB volatilizes to the atmosphere and is diluted by upwelling uncontaminated groundwater. Therefore, EDB concentrations measured in the surface water of the Quashnet River and bogs have been below the acute screening-level benchmark for aquatic organisms (554 micrograms per liter [µg/L]) and the chronic benchmark (31 µg/L) (AFCEE 1998).

2.2.3 Hydrologic Conceptual Model

The hydrologic conceptual model provides the basis for assessing the system performance in the hydrologic setting (Figure 2-2). The hydrologic setting includes aquifer characteristics, natural and operational stress-induced groundwater flow dynamics, groundwater and surface water interaction, and surface water flow and effluent discharge. The conceptual model is refined as new data become available and is a key tool for remedial system performance evaluation.

2.2.3.1 Groundwater Hydrology and Aquifer Characteristics

The hydrologic conceptual model for the FS-1 plume in the vicinity of the Quashnet River and bogs is presented in Figure 2-2. The aquifer in the FS-1 plume area is comprised of the Mashpee Pitted Plain (MPP), a fining-downward sequence of glacial outwash and proglacial lacustrine deposits that overlie Paleozoic crystalline bedrock. The MPP, deposited during the late Wisconsinan stage of continental glaciation, consists of deltaic glaciofluvial fine-to-coarse sand and gravel overlying glaciolacustrine medium-to-fine sand with silt. Extensive lenses of finer-grained sediment (glaciolacustrine fine sand and silt) occur in the basal portion of the section.

The aquifer underlying MMR and surrounding areas of western Cape Cod is designated a sole-source aquifer. The aquifer is undifferentiated vertically and is composed of sediment of the MPP and the Buzzards Bay and Sandwich moraines. In general, the aquifer is very productive, and most of the upper Cape Cod drinking water is obtained from this aquifer. Locally, fine-grained sediment lenses of limited lateral extent may make the aquifer unproductive locally. Overall the hydraulic conductivities of most MPP sediments range from approximately 125 to 300 feet per day (ft/day). In the vicinity of the Quashnet River and bogs complex, hydraulic conductivities of 90 to 150 ft/day have been determined based on the results of a pumping test conducted at extraction well 36EW0005 (AFCEE 2000i).

The thickness of the glacial outwash deposits varies between 150 to 220 feet in the bog area. Within the sandy outwash, there are deposits of interbeds of fine-grained sand, sandy silt, and silt. The interbeds vary in thickness from less than 1 foot to more than 10 feet and are frequent to sporadic in occurrence. Interbeds may be separated by up to 100 feet of massively bedded medium-grained sand (AFCEE 2001a).

Field investigations provided detailed stratigraphic information and physical parameter data on peat and organic soil in the Quashnet bogs area. The peat may be up to 41.5 feet thick as determined from drive-point sampling on the K2, K3, and K6 bogs (AFCEE 2000a). Generally, the peat has a low permeability, as determined by low purge rates observed during the collection of water samples from the drive points. Hydraulic conductivities measured from the peat range from 7.5×10^{-3} to 2.6×10^{-1} ft/day. Vertical hydraulic gradients across the organic material suggest a potential for upward groundwater flow. The peat is underlain by the glacial outwash deposits typical of the MPP. In general, the peat unit functions as an upper semiconfining layer. Groundwater discharge to the bog complex is controlled by peat thickness and river/bog channel geometry, with more discharge occurring in areas of low peat thickness, perimeter ditches, and interior channels in the bogs.

2.2.3.2 Surface Water Characteristics

Surface water within the study area is predominately derived from groundwater upwelling near the fringes of the developed bogs and wetlands. Water level contours and vertical hydraulic gradients from wells in this area indicate that the river and bogs are points of groundwater discharge. Flow in the Quashnet River is partially derived from outflow from Johns Pond, a kettle pond located to the west of the bog complex. River flow is controlled by a weir located on the northeast portion of Johns Pond. From there, the river flows east through the large cranberry bog and wetlands complex and then south to Waquoit Bay. The Massachusetts Department of Environmental Protection (DEP) has classified the Quashnet River as a Class B surface water body (e.g., suitable for recreational purposes and agricultural uses).

2.2.3.3 FS-1 EDB Groundwater Plume

The FS-1 EDB groundwater plume originated during the 1950s and 1960s from aviation fuel spilled during the testing of aircraft fuel-dump valves in staging areas adjacent to the southeastern end of the Otis Air National Guard Base runway. The hydrocarbon fraction underwent relatively rapid biodegradation and is no longer present in significant quantities in soil or groundwater. EDB, used as a fuel additive, degrades much more slowly in groundwater, and thus formed a plume originating at the staging areas. Changes in flight-line practices after the 1960s halted the fuel spills, eliminating the source of the plume. Subsequent recharge and groundwater underflow has flushed the source area, resulting in a detached EDB plume downgradient of the source area.

The trailing edge of the FS-1 plume is currently near the MMR boundary, approximately 700 feet downgradient (southeast) of the source area. The leading edge of the plume is discharging in the Quashnet Bog complex, where groundwater that originated in the vicinity of the source area returns to the surface. Based on assessment of groundwater velocities and source release timing, the plume probably began discharging to the bogs in the mid-1990s, but has been largely captured since April 1999 by the remedial system. Because of the generally low organic carbon content of aquifer materials on western Cape Cod (AFCEE 2002a), the plume is advecting throughout most of its length with negligible retardation. Beneath the bogs, EDB is strongly retarded within the thick organic-rich peat zones. The peat has very low hydraulic conductivity, however, so most discharging groundwater flows around the peat to reach the surface near the perimeter of the bog complex. Peat adsorption explains why the relatively small flux of water upwelling in the interiors of most of the bogs is EDB-free.

The plume, defined by EDB concentrations greater than the Massachusetts maximum contaminant level (MMCL) of 0.02 µg/L, is approximately 6525 feet long and up to 1200 feet wide (AFCEE 2001a). The plume is thickest at the discharge front where EDB is encountered at the water table and extends to a depth of 180 feet below ground surface (ft bgs). In October 2000, the estimated mass of EDB was 8.1 kg with a plume volume of 1.52 billion gallons (AFCEE 2001a).

Within the Quashnet Bog complex, EDB has been detected in surface water of the K6 bog at concentrations up to 1.23 μg/L (AFCEE 2000g) and continues to be detectable there. Before the current remedial system was activated in April 1999, EDB was also detected in the eastern ditch of the K2 bog. EDB has not been detected in the surface water of the K2 bog east ditch since December 1999. The Quashnet River appears to be an effective hydraulic boundary because groundwater samples collected from the K5 bog have never contained EDB. There have been sporadic detections of EDB in the Quashnet River as it enters the bogs (i.e., location 36SW0015), but groundwater modeling indicates that this EDB is derived from the Eastern Briarwood plume (AFCEE 2001a, 2002c).

2.3 DESCRIPTION OF THE REMEDIAL SYSTEM

The FS-1 remedial system was designed to reduce and, if possible, prevent EDB associated with the FS-1 plume from reaching the surface water of the Quashnet River and associated bog ditches without degrading or impacting the existing ecosystem. The remedial pilot system includes groundwater extraction, treatment and discharge/ infiltration, and construction of berms to separate the potentially contaminated Quashnet River and some of its tributaries from the adjacent cranberry bogs. The layout of the system is presented in Figure 2-2, Figure 2-3 and Figure 2-4.

2.3.1 Groundwater Extraction

Contaminated groundwater is intercepted using a deep extraction well and a series of shallow extraction wellpoints at the edges of the K2 and K6 bogs (Figure 2-4). The deep extraction well was designed to intercept and hydraulically contain the plume and thus reduce the time that the shallow extraction wellpoints would need to be in operation. The shallow wellpoints were designed to intercept the shallow groundwater (0 to 20 feet bgs) entering the adjacent bogs and surface water without causing dewatering.

2.3.1.1 Deep Groundwater Extraction

The deep groundwater extraction portion of the system consists of one well, 36EW0005, equipped with a submersible pump. The 8-inch-diameter extraction well was installed in

February 1999 and is located on the south side of the K1 bog. The well is screened from an elevation of -87 to -148 feet mean sea level (ft msl). The average pumping rate of the deep extraction well from May 2001 through April 2002 was 297 gallons per minute (gpm) (design pumping rate is 300 gpm).

2.3.1.2 Shallow Groundwater Extraction

Shallow groundwater is extracted using an SWP extraction system installed along the eastern side of the K2 and the northwestern side of the K6 bogs. This wellpoint system consists of a group of wells at 10-foot intervals connected to a manifold. A single centralized pump lifts water from the wells by producing a partial vacuum in the header and the riser pipes. The system was intended to pump at a rate that would intercept the shallow groundwater while not dewatering adjacent bog ditches or impacting water levels in the Quashnet River.

During the reporting period, the average flow rate from the SWP extraction system was 434 gpm (design flow rate was 450 gpm). The system operates such that individual SWPs may be turned on or off depending on where extraction is desired within the overall array. The available vacuum head is thereby roughly distributed among the open SWPs to achieve the desired flow. Ninety-five of the 175 SWPs were in operation from May through December 2001 (Figure 2-1) (AFCEE 2000a). In an effort to optimize the extraction of contaminated groundwater, the SWP system was reconfigured in January 2002 with 103 of the 175 SWPs in operation (Figure 2-4) (AFCEE 2002c).

2.3.2 Treatment System

Groundwater is pumped from the deep extraction well to the treatment plant and from SWPs to an 800-gallon steel holding tank and then to the treatment plant. The treatment system includes two 20,000-pound granular activated carbon (GAC) vessels that operate in a series. A process diagram of the treatment system is presented in Figure 2-3.

2.3.3 Treated Effluent Discharge

Treated water is discharged at a rate of 630 gpm to surface water and 120 gpm to a shallow groundwater infiltration trench. The discharge to the surface water is directed to the bubbler located at the northern extent of the K2 bog west ditch. The infiltration trench is located along the northern side of the K1 bog.

2.3.3.1 Surface Water Discharge

Treated water is discharged to the surface water at the beginning of the K2 bog west ditch at a rate of 630 gpm by means of a corrugated metal bubbler (north bubbler). The bubbler increases the level of dissolved oxygen (DO) by allowing the water to cascade into the ditch channel. The aeration is intended to provide acceptable DO concentrations for fish habitat and to meet the discharge standards established in 314 Commonwealth of Massachusetts Regulations (CMR) 4.05 (5 mg/L) and in the Mashpee Conservation Commission Order of Conditions (8 mg/L) (MCC 1999). The 8 µg/L guideline was later removed in the Amended Order of Conditions (MCC 2000).

2.3.3.2 Shallow Infiltration Discharge

The shallow infiltration trench was designed to mound the water table near the K1 bog in an effort to prevent groundwater containing EDB from entering the K1 bog and to improve the capture of the deep extraction well. Additionally, the trench was intended to increase the flow of the K1 bog ditches to improve the habitat for trout spawning. The infiltration trench is approximately 300 feet in length, 3 feet deep and is constructed of a 4 inch-diameter perforated pipe set in a gravel bed. The injection of 120 gpm has created a 1.0- to 2.5-foot groundwater mound (AFCEE 2000a).

2.3.4 Bog Separation

Earthen berms were constructed to separate the K2 bog from the potentially contaminated surface water in the K2 east ditch, and to separate the Quashnet River from the K6 bog (Figure 2-4). Geotechnical investigations were conducted before and after the berms were constructed (AFCEE 2000h), and a summary of berm construction is provided in the *Fuel Spill-1 Quashnet River and Bogs Separation Project Post-Construction Report* (AFCEE 2000e). The berms in the K2 area were constructed as designed and have successfully separated the flows. The berm in the K6 area experienced a subsidence in the section along the Quashnet River during construction. No additional work was conducted on the berm during the reporting period. However, since EDB is currently detected in the surface waters of the K6 bog (locations 36SW0019 and 36SW4188) and sporadically detected in the main channel of the Quashnet River (locations 36SW0003 and 36SW0015), separating the river from the K6 bog to limit contaminant migration is no longer necessary.

3.0 MONITORING ACTIVITIES

This section describes groundwater, surface water, and remedial system monitoring activities completed during the reporting period (May 2001 to April 2002). Between May and December 2001, surface water and groundwater monitoring were conducted as described in the *Final Quashnet River and Bogs System Pilot Test 2000 Annual Report* (AFCEE 2000a). Beginning in January 2002, groundwater monitoring was expanded to include the northern portion of the FS-1 plume and the source area (AFCEE 2002c). The treatment plant was monitored according to the *Final Quashnet River and Bogs Pilot Test Monitoring Plan at MMR* (AFCEE 1999b) and subsequent project notes (AFCEE 1999a, 2001b). FS-1 SPEIM monitoring activities and analyses were performed in accordance with the *Quality Program Plan* (QPP) (AFCEE 2000c).

3.1 HYDRAULIC MONITORING

During the reporting period, surface water and groundwater hydraulic monitoring activities were performed in accordance with the *Final Quashnet River and Bogs Pilot Test Monitoring Plan at MMR* (AFCEE 1999b) and modifications to the plan recommended in the 2001 annual report (AFCEE 2002c). Surface water monitoring activities included discharge (flow) measurements and stream elevation measurements at staff gauges proximal to the discharge measurement locations. Groundwater monitoring activities included synoptic water level measurements in monitoring wells and piezometers throughout the bog area, at upland locations, at the northern part of the FS-1 plume, and near the shallow wellpoints, extraction well 36EW0005, and the infiltration trench. In addition, daily precipitation measurements were obtained from the Otis Air National Guard weather station located approximately 1.25 miles northwest of the Quashnet bogs.

3.1.1 Surface Water Discharge and Elevation Measurements

Surface water discharge was measured quarterly between May 2001 and April 2002. Discharge measurements were made at locations 36SG0201A, 36SG0301C, and 36SG0303A in the K2 bog, and 36SG0015A, 36SG0200A, and 36SG0001B in the

Quashnet River (Figure 3-1 and Table 3-1). With the onset of freezing temperatures, the bogs were flooded in mid-January 2002 to protect the cranberry plants. The bogs were then drained in mid-April when daily low temperatures were consistently above freezing. Thus, there were no measurements at most of the locations in January. During the reporting period, 96 percent of the planned staff gauge measurements and 63 percent of the discharge measurements were taken. The following exceptions are noted:

- No discharge measurements were taken at 36SG0201A in July 2001 or May 2002 due to low flow conditions in the K2 bog east ditch or in January 2002 because the bogs were flooded for frost control.
- No discharge measurements were taken at 36SG0303A in July and October 2001 or May 2002 due to low flow conditions in the K2 bog east ditch or in January 2002 because the bogs were flooded for frost control.
- No discharge measurements were taken at 36SG0015A, 36SG0200A, or 36SG0301C during January 2002 because the bogs were flooded for frost control.
- All discharge measurements scheduled for April 2002 were taken in May 2002 because the bogs were flooded for frost control.

Discharge rates were calculated using data collected from staff gauges and flow velocity measurements.

3.1.2 Groundwater Level Measurement Activities

Groundwater levels were measured semiannually in May through December 2001. Beginning January 2002, AFCEE implemented the FS-1 SPEIM monitoring plan presented in the *Final Quashnet River and Bogs 2001 Annual System Performance and Ecological Impact Monitoring Report* (AFCEE 2002c). This monitoring plan is intended to establish a baseline prior to the startup of the expanded FS-1 remedial system, and to help determine changes in groundwater and flow patterns in the vicinity of the bogs. According to the aforementioned plan, groundwater levels were measured quarterly in January through April 2002 (Figure 3-2, Table 3-2) (AFCEE 2000a, 2002c). Both the shallow wellpoint and deep extraction well systems were operating during the synoptic measurements. During the reporting period 100 percent of the planned hydraulic measurements were taken. Groundwater levels were also recorded during groundwater

physicochemical and chemical monitoring activities. These groundwater levels were measured over a period of days, differing from the synoptic measurements where measurements from all selected locations were obtained in a single day.

3.2 GROUNDWATER MONITORING ACTIVITIES

Groundwater physicochemical and chemical monitoring activities were performed in accordance with the *Final Quashnet River and Bogs Pilot Test 2000 Annual Report* (AFCEE 2000a) from May through December 2001. During January through April 2002, groundwater was monitored in accordance with the *Final Quashnet River and Bogs 2001 Annual System Performance and Ecological Impact Monitoring Report* (AFCEE 2002c). Additionally, during August 2001 nine monitoring wells were sampled at the request of the regulatory agencies (AFCEE 2002d). Selected shallow extraction wellpoints were sampled quarterly for EDB and physicochemical parameters during the reporting period. A detailed outline of groundwater sampling activities is provided in Table 3-2, and sampling locations are depicted in Figure 3-3. During the reporting period 97 percent of the planned samples were collected with the following exceptions:

- Monitoring wells 36MW1039A,C could not be sampled during October 2001, and January and March 2002 because the wells had been vandalized (filled with woodchips).

3.3 SURFACE WATER MONITORING ACTIVITIES

Surface water samples were collected monthly for physicochemical parameters and/or EDB from May through December 2001 (AFCEE 2000a). Samples were collected quarterly from January through April 2002 with the exception of K6 bog locations 36SW0019 and 36SW4188, which were monitored monthly (AFCEE 2001c, 2002c). The town of Mashpee requested that two locations (36SW0031 and 36SW0032) downstream of the developed bog complex be sampled for EDB and physicochemical parameters during 2001. Additionally during the reporting period, temperature and DO were measured on an hourly basis at 36SW0010 (upstream of the treatment system discharge) and 36SW0300 (immediately downstream of the treatment system discharge).

A detailed outline of surface water sampling activities is provided in Table 3-1 and sampled locations are depicted in Figure 3-1. During the reporting period, 96 percent of the planned samples were collected with the following exceptions:

- No samples were collected from 36SW0221 during October 2001 due to low-flow conditions in the bog ditch.
- No samples were collected from 36SW0019 and 36SW4188 from January through April 2002 because the bogs were flooded for frost control.

3.4 REMEDIAL SYSTEM MONITORING

A project note (AFCEE 2001b) was distributed during the period of performance which further modified the *Final Quashnet River and Bogs Pilot Test Monitoring Plan* (AFCEE 1999b), and the National Pollutant Discharge Elimination System (NPDES) permit exclusion requirements (AFCEE 2000d; EPA 1999b). This project note change is the latest in a sequence of changes that have been made to the original documents: (1) agreement which streamlined the in-plant sampling program (AFCEE 1999a), (2) letter which amended the NPDES exclusion requirements (EPA 1999b), and (3) revisions to the compliance monitoring (AFCEE 2001b).

3.4.1 Treatment System Chemical Monitoring

Samples were analyzed monthly for EDB at four locations in the treatment system: plant influent from the deep extraction well (36EW0005), plant influent from the shallow extraction wellpoints (36PLT01005), the intermediate sampling port after the first GAC unit (36PLT01002 or 36PLT01004), and the plant effluent (36PLT01003) (Figure 2-3). Between May 2001 and April 2002, samples were analyzed quarterly for alkalinity, biological oxygen demand (BOD), chemical oxygen demand (COD), total and dissolved organic carbon, and total dissolved and suspended solids. Table 3-3 summarizes the treatment system monitoring during the reporting period.

3.4.2 Treatment System Physicochemical Monitoring

Water quality parameters (temperature, DO, pH, specific conductance, oxidation-reduction potential [ORP], and turbidity) were monitored biweekly from the influent from the deep extraction well, influent from the shallow extraction wellpoints, combined influent, intermediate sampling port after the lead GAC unit, and from the treatment plant effluent (Figure 2-3, Table 3-3).

3.4.3 Treatment System Operations Monitoring

During the process of maintaining the treatment plant, a variety of operational parameters are recorded. The vacuum pressure is recorded to monitor the operation of the SWP extraction system. Differential pressure across the lead and lag vessels is documented to track the loading of the GAC units. Flow rates are recorded for the deep well, shallow extraction wellpoints, combined influent, discharge to the bubbler, and discharge to the infiltration trench. These parameters are also recorded automatically once every hour by the control system at the Sandwich Road Treatment Facility.

3.5 ECOLOGICAL BASELINE SURVEY OF A SPHAGNUM-CRANBERRY BOG NEAR THE FS-1 REMEDIAL SYSTEM

During the spring and summer of 2002, AFCEE conducted an ecological baseline survey of the sphagnum bog located north of Grafton Pocknet Road. The survey was performed to satisfy a requirement in the town of Mashpee's Amended Order of Condition regarding planned construction and operation of the future expanded FS-1 remedial system. The results of the survey are presented in Appendix D of this report.

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4.0 RESULTS

This section presents the evaluation of the data collected during the reporting period (May 2001 through April 2002). Data collected during the reporting period include hydraulic monitoring data, groundwater analytical data, surface water analytical data, and treatment plant analytical and flow data. Data collected from May through October 2001 were presented in the 2001 semiannual report dated February 2002 (AFCEE 2002d). Data collected during the third and fourth quarters (November 2001 through April 2002) are discussed and presented in Appendix A (Data Summary Report) and Appendix B (Data Report).

4.1 HYDRAULIC MONITORING

The assessment of FS-1 hydraulic monitoring includes, precipitation, surface water elevation and discharge measurements and groundwater level measurements. Hydraulic monitoring was performed quarterly through the reporting period.

4.1.1 Precipitation and Recharge

The precipitation measurements at MMR, including both daily and monthly precipitation and cumulative rainfall for the reporting period from May 2001 to April 2002, are presented in Figure 4-1. Daily precipitation totals during the period surpassed one inch per day on eight separate dates. A maximum daily precipitation of 2.44 inches was recorded on 20 August 2001. Monthly total precipitation for the monitoring period ranged from a low of 1.84 inches in February 2002 to a high of 4.65 inches in August 2001. The total precipitation from 01 May 2001 to 30 April 2002 was only 37.75 inches, significantly lower than the 30-year average of 46.57 inches on Cape Cod.

The precipitation is distributed evenly throughout the year, as shown by the general steady rise for the cumulative rainfall curve (Figure 4-1). Two noticeably prolonged dry (no-precipitation) periods occurred during May 2001 and November 2001, respectively. Each of the periods was followed by a rainy period that contributed to the steep rise on the cumulative rainfall curve.

Recharge to the groundwater is a function of precipitation and evapotranspiration. While the precipitation is evenly distributed throughout the year, there is less recharge to the groundwater due to significantly more evapotranspiration during the summer/fall months. Less recharge to the groundwater during the period may contribute to the general groundwater seasonal trend at MMR in that the groundwater levels typically increase from the spring to the summer and decrease from the fall to the winter.

4.1.2 Surface Water Flow Rate and Groundwater Discharge

Surface water discharge results for this reporting period are presented in Table 4-1 and Figure 4-2. Surface water discharge results are used to identify areas that groundwater is discharging to the Quashnet River and bogs. Three monitoring locations, 36SG0015A, 35SG0200A, and 36SG0001B, are in the Quashnet River (Figure 3-1). Location 36SG0015A is at the surface water entrance to the active Quashnet bogs from the west. Location 36SG0001B is in the Quashnet River where it exits the bog complex. Location 35SG0200A is at the midpoint of the river where it separates the upper bogs (K2, K3, and K4) from the lower bogs (K5 and K6).

Flow rates at these locations in the Quashnet River showed considerable ranges, but exhibited a similar trend. The flow rates at 36SG0001B ranged from 3.06 cubic feet per second (cfs) in January 2002 to 7.79 cfs in April 2001. At 36SG0015A, the flow rates were between 0.76 and 3.55 cfs. The flow rates were higher in the spring/early summer and lower in the late fall/winter (Figure 4-2). With the onset of freezing temperatures, the bogs were flooded in mid-January to protect the cranberry plants. The bogs were then drained in mid-April when daily low temperatures were consistently above freezing. Thus, there were no measurements at the entry point (36SG0015A) and midpoint (36SG0200A) of the river.

The groundwater discharge rate to the bogs and river segment along the bogs is the difference between the bog entrance point (36SG0015A) and the bog exit point (36SG0001B). Since the FS-1 treatment system also discharged 1.67 cfs (750 gpm) to

the bogs, the groundwater discharge rate [$Q_{(gw\text{-}discharge)}$] can be calculated based on the following equation:

$$Q_{(gw\text{-}discharge)} = Q_{(36SG0001B)} - Q_{(36SG0015A)} - Q_{(discharge\ of\ treatment\ system)}$$

where Q's are the flow rates at various locations.

The calculated groundwater discharge rates to the bogs were between 2.25 and 3.03 cfs, with a median of 2.7 cfs (Figure 4-2). This confirmed that the Quashnet bogs are an area of significant groundwater discharge. Even though the flow rates at the locations in the Quashnet River varied considerably throughout the year, the groundwater discharge to the bogs was fairly consistent.

Most of the increased flow occurred at the northern bogs (K2, K3, and K4), as indicated by the flow rate at the midpoint location (36SG0200A). More than 75 percent of the total groundwater discharge to the Quashnet bog complex was from the northern bogs (Figure 4-2).

The interior surface water monitoring locations along the perimeter ditch of the K2 bog exhibited fairly constant flow rates throughout the reporting period.

4.1.3 Groundwater Levels and Flow Field

Groundwater flow and the hydraulic effect of the shallow extraction wellpoints and the deep extraction well were evaluated through assessment of groundwater level data. Water level data for this reporting period (01 May 2001 to 30 April 2002) are presented in Table 4-2 and Table 4-3. Table 4-2 lists the water level data from synoptic hydraulic measurement data and Table 4-3 presents the water level data from groundwater physicochemical and chemical monitoring activities. The monitoring locations are shown in Figure 3-2 and Figure 3-3.

Groundwater elevation data collected from 22 January 2002 were contoured to produce water table and potentiometric maps. Figure 4-3 shows the shallow groundwater (water table) elevation contours in the aquifer from wells with midscreen elevations above mean sea level, and surface water elevation data at the bogs. The water table contours are strongly influenced by the local topography and surface water features. Figure 4-4 depicts groundwater elevation contours in the deeper portions of the aquifer using the wells with midscreen elevations below mean sea level. The potentiometric surface for the deeper portion of the aquifer reflects the regional hydraulic gradient, which generally shows flow from north to south, the local discharge of groundwater to the Quashnet bogs, and the effects of groundwater extraction at 36EW0005. Figure 4-3 and Figure 4-4 both indicate groundwater discharge to the bogs.

Hydrographs for selected monitoring wells near the bogs are presented in Figure 4-5. During the reporting period, the highest groundwater elevations were recorded in March 2002 and the lowest groundwater elevations were recorded in October 2001. With the onset of freezing temperatures, the bogs were flooded in January 2002 to protect the cranberry plants. The bogs were then drained in mid-April 2002 when daily low temperatures were consistently above freezing. Therefore, the groundwater level measurements in January and March 2002 were conducted in the bog-flooded condition. The effect of the bog flooding caused the relatively higher water levels at monitoring locations near the bogs (Figure 4-5). The Quashnet River and bogs treatment system was continuously operated at a flow rate of 750 gpm during the reporting period. Thus, the hydraulic impact from the treatment system on the groundwater levels was constant through the reporting period.

Hydrographs for monitoring wells in the central and northern parts of the FS-1 plume are presented in Figure 4-6. In general, the groundwater levels showed a decreasing trend. The trend was probably caused by the overall water level drop in the area due to lowered precipitation for the reporting period (20 percent less than the 30-year average). Overall, the water level variation in the FS-1 area was consistent with the general seasonal water

level seasonal trend at MMR in that the groundwater levels typically increase from the spring to the summer and decrease from the fall to the winter.

A vertical hydraulic gradient analysis was carried out to delineate the groundwater flow in the vertical direction and the hydraulic impact from the remediation system. Gradients were calculated using the convention of subtracting the shallow from the deep potentiometric heads at a same location. Negative gradients, therefore, represent downward flow. Figure 4-7 depicts the vertical gradients and their variation at selected locations throughout the reporting period. Strong upward hydraulic gradients were observed in monitoring wells directly east of the Quashnet bogs, at locations 36MW1012A,B,C; 36MW1014A,B; and 36MW0132A,B,C. This indicates the upwelling nature of the groundwater to the bog and the SWP extraction system effect in the shallow groundwater zone. The vertical upward gradients at these locations decreased during the bog-flooded period, resulting from the higher water levels in the bogs. The water levels in the bogs during flooding were 2 to 3 feet higher than the unflooded condition. Thus, flooded bogs appeared to have resulted in reduced discharge of groundwater to the bogs, as suggested by groundwater modeling results.

The monitoring well west of the bogs (36MW1011A/B) also showed an upward gradient during unflooded condition, indicating that the bogs also received groundwater discharge from the west side. When bogs were flooded, however, the vertical gradient at the location became slightly downward.

The monitoring wells immediately east and north of extraction well 36EW0005 (36MW131A,B,C; 36MW1313A,B,C,D,E; and 36MW1010A,B,C,PZ) exhibited more complex patterns relative to the pumping screen interval (-87 to -148 ft msl). The vertical gradients appeared to be mostly flat near the pumping screen interval; whereas, there were downward gradients in the shallower zone (36MW1010C,PZ and 36MW131B,C). It indicates the positive effect of the deep extraction well on the groundwater flow system by reducing upward flow to the bogs.

The vertical hydraulic gradients in the monitoring wells in the central and northern portion of the FS-1 plume area (represented by the dashed-line pattern in Figure 4-7) were mostly flat, suggesting predominantly horizontal groundwater flows.

Analyses of the groundwater level data provided the following insights on the groundwater flow in the bog area:

- The water table map and the potentiometric surface for the deeper portion of the aquifer both reflect the regional hydraulic gradient, the local discharge of groundwater to the Quashnet bogs, and the effects of groundwater extraction at 36EW0005.
- The groundwater monitoring locations immediately east of the Quashnet bogs all had upward hydraulic gradients, indicating positive hydraulic impact from the SWP extraction system. An upward flow was shown by the wells near the shallow extraction wellpoints. The monitoring wells near the deep extraction well (36EW0005) all had either upward or downward flow toward the well pumping screen.
- Flooding the bogs reduces the discharge of groundwater to the bogs.

4.2 GROUNDWATER CHEMISTRY

This section presents the results of physicochemical and chemical groundwater monitoring conducted during the reporting period (as described in Table 3-2).

4.2.1 Groundwater Physicochemistry

Field measurements of physicochemical parameters (temperature, DO, pH, specific conductance, ORP, and turbidity) from groundwater monitoring wells and shallow extraction wellpoints are summarized in Table 4-4. Sampling locations are shown on Figure 2-4 and Figure 3-3. General water quality indicators (temperature, pH, specific conductance, and turbidity) continue to show that groundwater is acceptable for discharge to surface water after equilibration with air to ensure adequate DO. The physicochemical parameters are primarily used as indicators during the purging of monitoring wells; stable readings indicate that water representative of aquifer conditions is being sampled (AFCEE 2000c).

Temperatures observed during the reporting period ranged from 9.92 to 14.84 degrees Celsius (°C) in monitoring wells, 4.49 to 10.71 °C in piezometers, and 7.39 to 16.07 °C in the shallow wellpoints (Table 4-4). Because temperatures are measured in a flow-through cell at the surface along with the other field parameters, some of the variation is attributable to variations in the ambient temperature. The remaining variation reflects proximity to the surface and the influence of upwelling groundwater from deeper levels. Specific conductance ranged from 38 to 279 microsiemens per centimeter (µS/cm). All but the highest values are similar to the range observed in surface water and typical of values elsewhere on Cape Cod (usually less than about 100 µS/cm). Values within each well were generally consistent, showing a range of 8 µS/cm or less, but with occasional spikes.

Measured pH values ranged from 5.02 to 8.99 during the reporting period, and averaged 6.3 ± 1.26 (two standard deviations). The average is unchanged from the previous reporting period, but the range is slightly greater, most likely a consequence of the extended monitoring well network encompassing a wider range of geochemical environments. For comparison, groundwater pH values on upper Cape Cod are typically 6 to 6.5. Lower values in and around the FS-1 plume may reflect mineralization to carbon dioxide of the hydrocarbon components that originally accompanied the EDB; whereas, higher values are likely attributable to greater alkalinity due to processes unrelated to the plume.

Measurements of DO and ORP ranged from 0.15 to 11.57 mg/L and -308 to 483 millivolts (mV), respectively, in monitoring wells, and from 1.91 to 14.21 mg/L and 164 to 457 mV, in the shallow wellpoints. Most monitoring wells continued to exhibit oxidizing characteristics (DO greater than 2 to 3 mg/L and ORP greater than 0 mV), averaging 4.36 mg/L and 172 mV. During the previous annual reporting period, the shallow wellpoints exhibited a mixed character, with high DO (near 10 mg/L) but low ORP (less than 0 mV). During the current reporting period for the shallow wellpoints, both DO and ORP indicate well oxygenated conditions, averaging 8.50 mg/L and 312 mV.

Most turbidity values were less than 10 nephelometric turbidity units (NTU), indicating very low amounts of suspended material in the sampled groundwater from monitoring wells and shallow wellpoints. For the monitoring wells and piezometers, 30 of 160 measurements exceeded 10 NTU, with a maximum value of 190 NTU. For the shallow wellpoints, only seven of 61 measurements exceeded 10 NTU, with a maximum value of 87 NTU. These high values are probably related to varying degrees of disturbance of downhole conditions during sampling, suspending fine-grained material that is not normally part of the water column. Such disturbance is problematic for analyses of total metals or total organic carbon, but neither of these analyses were conducted during the reporting period. Mildly elevated turbidity is unlikely to affect measured EDB concentrations or the other field parameters. In January 2002, well 36PZ1003 was extremely turbid (1357 NTU); the well cap was missing and there was dirt in the piezometer, so no sample was collected for EDB analysis.

4.2.2 Groundwater Ethylene Dibromide Results

Groundwater monitoring locations are depicted in Figure 3-3, and results are presented in Table 4-4. Measured EDB concentrations ranged from nondetect outside the plume to 21.3 μg/L in the core of the plume (36MW1038B, 21 January 2002). Core concentrations are little changed since initial plume characterization in 2000, when a maximum concentration of 29 μg/L was detected.

The expanded monitoring-well network implemented for the current reporting period, augmented by migrated historical observations, permits construction of a synoptic view of the plume in March 2002. The FS-1 EDB plume is shown in plan view in Figure 4-8, and in cross section along its axis in Figure 4-9. Figure 4-8 also includes the locations of the three proposed extraction wells for the complete FS-1 remedial system (AFCEE 2001a). These schematic views are based on the last synoptic mapping in October 2000, with contour topology updated as needed to reflect concentrations observed in March 2002. Elevated concentrations (greater than 5 μg/L) in the trailing edge are inferred based on borehole detections during construction of 36MW0603A in 1998, migrated downgradient at approximately 1.5 ft/day (Section 4.2.2.1 and Appendix I in AFCEE

2001a). The plume has evolved only slightly since the last synoptic mapping in October 2000 (AFCEE 2001a). Concentrations at most monitoring wells have declined, in some cases by more than 25 percent. The larger declines probably reflect the heterogeneity of the plume, with local hot spots migrating away from individual monitoring wells, but the predominance of declining concentrations, even at low EDB levels, argues that some attenuative process is also operating. Studies elsewhere (Weintraub et al. 1986; Pankow and Cherry 1996) have suggested that abiotic hydrolysis is probably an important mechanism of EDB degradation, resulting in a half-life of 5.4 to 7.2 years in groundwater at a temperature of 12.2 °C. An assessment of the FS-29 plume suggested that a disappearance half-life (encompassing dispersion as well as degradation) of seven years is compatible with current concentrations and probable plume history (AFCEE 2002b).

The core of the plume continues to be defined by the high concentrations measured in 36MW1038B (17.7 µg/L in March 2002, down from 29 µg/L in 2000) at an elevation of -104.6 ft msl. The trailing edge continues to be defined by 36MW0603A at an elevation of -86.8 ft msl. Here, concentrations have declined from 1.80 µg/L in 2000 to 0.255 µg/L in March 2002. Concentrations of most other in-plume wells upgradient of the bogs have shown similar declines. Beneath the bogs, the plume becomes complex because of upward vertical hydraulic gradients and the effects of the deep extraction well and the shallow wellpoints. Subsurface detections of EDB extend only as far south (downgradient) as the boundary between the K2 and K6 bogs, in 36MW1001B (0.051 µg/L at an elevation of -62.87 ft msl). The deeper and shallower wells at this location (36MW1001A and 36PZ1001) are both nondetect for EDB. However, detections in surface water (see Section 4.3.2) occur in the southern portion of the K6 bog, approximately 550 feet south of the 36MW1001 well cluster.

EDB concentrations in groundwater over time are presented in Figure 4-10 for the eight wells in and near the bogs that have been measured frequently since the start of the FS-1 remedial system in March 1999. Among these wells, the highest concentration observed during the reporting period was 5.42 µg/L in 36MW0132B. To illustrate trends, first- and second-year data are also plotted, along with influent EDB concentrations from the deep extraction well (36EW0005) and the SWP system (36PLT01005). Although results

in individual wells show considerable variation with time, all wells show a general downward trend over the three-year period of operations.

During the current monitoring period, three wells exhibited appreciable increases in the January and/or March 2002 sampling rounds (36MW0131A, 36MW0132C, and 36MW0136). 36MW0131A is deep (-130.4 ft msl) and 275 feet southeast of the deep extraction well (36EW0005); the increase here is attributable to the continuing southward advection of the high-concentration core of the plume. The deep extraction well captures only the western portion of the plume, permitting the eastern portion to migrate south toward the bogs. The shallower well here (36MW0131B at -83.2 ft msl) is near the top of the plume and has exhibited low (near 0.2 μg/L) and nearly constant EDB concentrations since late 2000. 36MW0132C is located farther downgradient, adjacent to the southern end of the K2 bog and the midsection of the shallow wellpoint fence. The increases in this well might also be related to arrival of higher EDB concentrations uncaptured by the deep extraction well, but could also reflect a change in plume dynamics related to the regional decline in water levels caused by drought conditions that have persisted since 2000. 36MW0136 (-89.29 ft msl) is located on the southeastern edge of the plume boundary, and EDB concentrations have fluctuated above and below the MMCL since October 1999. The increase in EDB concentrations at 36MW0136 may be due to the heterogeneity of the uncaptured portion of the plume. The deep well here, 36MW0132A at -133.2 ft msl, showed a slight increase in January 2002 but then declined to its lowest level yet in March 2002 (0.839 μg/L). 36MW1001A, deep beneath the northern part of the K6 bog, and 36MW0133, beneath the southern part of the same bog, continued to be nondetect for EDB, showing that the plume is no longer present at depth there. 36MW0131B declined only slightly to 0.11 μg/L, and 36MW1003A was not sampled during the reporting period.

The pattern of plume upwelling along the eastern margins of the K2 and K6 bogs is revealed by EDB measurements from selected wellpoints. Accurate knowledge of the distribution of upwelling EDB is important for optimizing the SWP system, determining which wellpoints should be turned off and which need to be left operating. EDB

concentrations for the shallow wellpoints during the current reporting period are listed in Table 4-4. The spatial distribution of EDB in the shallow wellpoints is depicted in Figure 4-11. The data show that the highest EDB concentrations occur in the southwest branch of the SWP system between the K2 and K6 bogs, with the maximum detection of 1.09 µg/L occurring in 36EW4140. A second significant area of elevated EDB occurs in the midsection of the northern branch adjacent to the K2 bog, with a maximum detection of 0.458 µg/L. The eastern branch of the SWP extraction system, along the northern edge of the K6 bog, contains no detections of EDB. This pattern is essentially unchanged from the previous reporting period (AFCEE 2002c).

For selected wellpoints, EDB concentrations over time since startup of the remedial system in April 1999 are depicted in Figure 4-12. The selected wellpoints are listed from north to south and subdivided into four groups for readability of the graphs. They are distributed evenly throughout the wellpoint array, thus sampling clean groundwater as well as zones of EDB upwelling. As noted on the figure, several records are composites derived from two wellpoints. In several instances, a wellpoint could not be sampled due to mechanical problems (e.g., broken valve or frozen) so an adjacent wellpoint was sampled instead. Wellpoints with 1999 concentrations near 1 µg/L or less exhibited dramatically lower concentrations in 2001, and continued to do so during the current reporting period, with final concentrations generally less than 0.2 µg/L. Most wellpoints with low early concentrations (less than 0.5 µg/L) have declined, often to less than 0.02 µg/L (the MMCL). Two exceptions to this trend are 36EW4090 and 36EW4140, both located in the system branch between the K2 and K6 bogs. Concentrations at 36EW4090 have remained relatively constant near 0.5 µg/L during the three years of monitoring; whereas, concentrations at 36EW4140 had often been 0.05 µg/L or less, but shot up to 1.09 µg/L in March 2002. These trends reflect the heterogeneous distribution of EDB within the plume.

EDB concentrations and trends in the portions of the plume upgradient of the remedial system are depicted in Figure 4-13 and Figure 4-14, which compare measured concentrations for selected monitoring wells to concentrations predicted by the FS-1 groundwater model (AFCEE 2001a). These figures trace plume evolution since 30

October 2000. Three locations are plotted for the trailing edge (Figure 4-13); the model overpredicts EDB concentrations at all three. The extreme case is 36MW1036B (1000 feet downgradient from the trailing end of the plume and screened at -113.6 ft msl near the middle of the plume), where modeled concentrations are higher than measured concentrations by a factor of four or more. Two locations exhibit trends similar to the measured concentrations; at the third location (36MW1036C, screened at -64.7 ft msl near the top of the plume), concentrations declined slightly over the 18 months of record, from 0.056 μg/L to 0.043 μg/L; whereas, the model predicted a substantial increase, from 0.078 μg/L to 0.645 μg/L. These observations show that the model is conservative for the trailing edge, with higher initial concentrations and slower dissipation than has been observed.

In the central part of the FS-1 plume (Figure 4-14), measured concentrations at eight locations have shown only slight declines, except in monitoring well 36MW1039B. This well, located near the western edge of the plume, had the lowest measured concentrations and declined by approximately a factor of 3. Model-predicted trends were generally similar to measured trends, but concentration levels were somewhat different. At concentrations less than 2 μg/L, the model overpredicted concentrations by up to a factor of 2; whereas, at higher concentrations, the model underpredicted initial concentrations by about 25 percent and showed more rapid dissipation, with final concentrations too low by as much as a factor of 4. The performance of the model could be improved by refining the initial concentrations (creating a new plume shell) and reducing dispersion (smaller physical dispersion, or finer discretization to minimize numerical dispersion).

In summary, EDB measurements in groundwater have shown that:

- The plume has changed little since the last synoptic mapping in 2000. The plume continues to extend from 36MW0603A, which defines the trailing edge to the north, to surface-water EDB detections in the K6 bog, which define the leading edge.
- Subsurface detections of EDB extend no further south than the border between the K2 and K6 bogs.
- The core of the plume remains upgradient and slightly east of the deep extraction well (36EW0005).

- Concentrations have generally decreased during the three years of remedial system operation.
- The deep extraction well (36EW0005) has cut off the western portion of the plume, but the eastern portion appears to be bypassing this well, consistent with wellfield design predictions (AFCEE 2001a), leading to higher EDB detections in 36MW0131A.
- EDB upwelling in the perimeter ditches is localized between the K2 and K6 bogs and east of the K6 bog, similar to the pattern reported in the previous annual report, suggesting that the current pattern of SWP operation is appropriate.
- The FS-1 groundwater model using the 2000 FS-1 plume shell overestimates EDB concentrations in peripheral monitoring wells compared to the observational record, showing that model results are conservative with respect to the actual size of the plume.
- The FS-1 groundwater model using the 2000 FS-1 plume shell underestimates EDB concentrations in interior monitoring wells compared to the observational record, indicating that model results underestimate the actual mass of the plume.

4.2.3 Source Area Groundwater Chemistry

EDB was not detected in the groundwater of the source area wells. Five VOCs were detected in the source area wells (Figure 3-3, Table 4-4 and Table 4-5). Although four VOCS (ethylbenzene [maximum contaminant level (MCL) = 700 µg/L], toluene [MCL = 1,000 µg/L], ortho-xylene, and meta- plus para-xylene [MCL for total xylenes = 10,000 µg/L]) were detected in monitoring wells 36MW0002 (midscreen elevation 54.29 ft msl) and 36MW0007 (midscreen elevation 56.20 ft msl) during January and March 2002, all were below their respective MCLs and decreased between the January and March events. These compounds are generally associated with petroleum products, e.g., aviation gasoline. The low concentrations and declining trends indicate that there is no continuing source for the FS-1 plume and that natural attenuation will soon degrade these compounds entirely. These compounds do not appear to be migrating because the deeper well 36MW0015 (midscreen elevation -21.75 ft msl) and the downgradient well 36MW0010A (midscreen elevation 35.60 ft msl) do not contain these compounds (Figure 3-3). Groundwater associated with fuel spills is usually anoxic due to microbial degradation of these compounds. The groundwater at wells 36MW0002 and 36MW0007 contained low DO concentrations near or below 1 µg/L and low or negative ORP

indicating reducing conditions. The groundwater at wells 36MW0010A and 36MW0015 contained DO concentrations near saturation and ORP measurements between 153 and 441 mV indicating oxidizing conditions. Thus, the water quality results confirm the VOCs measured in groundwater from 36MW0002 and 36MW0007 are not migrating in the aquifer. The fifth VOC, chloroform (MCL = not available), was detected in 36MW0007 (2.78 µg/L) and 36MW0015 (0.36 µg/L) during the March 2002 sampling event. Because chloroform has not been identified in laboratory blanks and its occurrence is poorly correlated with that of the other VOCs, it is most likely biologically derived.

Thirteen metals were detected in groundwater samples from the source area wells (Figure 3-3, Table 4-5). Barium, calcium, iron, magnesium, manganese, potassium, and sodium were detected in groundwater samples from all the wells. The probable sources of barium, calcium, magnesium, potassium, and sodium were weathering of minerals and precipitation. Lead was detected in wells 36MW0002 and 36MW0007. These wells also contain the petroleum products. The source of the lead was probably the aviation gasoline spilled in the source area. The presence of the iron and manganese was probably due to dissolution of grain coatings in the aquifer matrix under the reducing conditions created by the fuel spill. Arsenic and chromium were detected at low concentrations in 36MW0007 (Table 4-5). Nickel was detected in 36MW0010A. The concentrations of the metals detected in the source area groundwater samples were below their respective MMCLs (see Section 4.5). However, lead exceeded the EPA and DEP action level of 15 µg/L in monitoring wells 36MW0002 and 36MW0007 (Table 4-5).

4.3 SURFACE WATER CHEMISTRY

Surface water was sampled to monitor potential human health and ecological risks associated with EDB-contaminated groundwater upwelling to the Quashnet River and bog ditches. Water quality parameters were also monitored to evaluate potential ecological impacts associated with the discharge of treated groundwater to surface water in the K2 bog and the infiltration trench in the K1 bog (AFCEE 1999b).

4.3.1 Surface Water Quality Parameters

Water quality parameters (i.e., temperature, DO, pH, specific conductance, ORP and turbidity) measured in samples collected from surface water locations during the reporting period are presented in Table 4-6. In accordance with an agreement with the regulatory agencies, hourly temperature and DO measurements from the K1 and K2 bogs are presented graphically in Figure 4-15, Figure 4-16, Figure 4-17, and Figure 4-18.

Surface water samples were collected both upstream and downstream of the treatment system discharge bubbler. Potential ecological impacts were determined by comparing temperature, DO, and pH measurements at locations downstream and upstream of the treatment system discharge with the Massachusetts Regulation 314 CMR 4.00, Surface Water Quality Standards (AFCEE 1999b)

The variability inherent in these measurements due to time of day, cloudiness, and precipitation can obscure short-term differences.

4.3.1.1 <u>Temperature</u>

The temperature of the Quashnet River and bog ditches was influenced by seasonal variations in ambient air temperature, the influx of groundwater, discharge of treated groundwater, and the manipulation of water levels associated with cranberry-growing activities (e.g., flooding the bogs) and fisheries management (i.e., managing herring runs to Johns Pond).

During the reporting period, the temperature of the Quashnet River and bog ditches ranged from 1.32 °C (location 36SW0036 on 28 December 2001) to 23.50 °C (location 36SW0036 on 25 July 2001) (Table 4-6). The temperature measured in the surface water of the K2 bog west ditch showed the lowest range between winter and summer (6.90 to 14.85 °C). The temperature of the upper K2 bog west ditch was moderated by the discharge of treated groundwater. The annual mean temperature of the treatment system effluent was 10.60 ± 0.51 °C. The temperature measured in the surface waters of the K1 bog ditches ranged from 4.70 to 17.30 °C, followed by the surface waters of the K2 bog

east ditch, 3.73 to 18.15 °C, the Quashnet River, 4.51 to 21.91 °C, and the K6 bog ditches, 1.32 to 23.50 °C.

In general, the treatment system surface water discharge warms surface water of the K2 bog west ditch from mid-fall (October) to early spring (March) and cools the surface water from mid-spring (April) through mid-fall (October). The difference between the daily mean temperatures (using data collected hourly) measured at locations 36SW0010 (upstream of the treatment system discharge) and 36SW0300 (downstream of the treatment system discharge) ranged from -3.94 °C in August 2001 to 2.82 °C in January 2002 (Figure 4-15 and Figure 4-17). The surface water discharge from the treatment system exceeded the acceptable criteria for temperature (a rise in temperature of less than 2.8 °C [314 CMR 4.05]) periodically from December 2001 through March 2002. The temperature exceedances measured at the end of December 2001 through March 2002 occurred when the bogs were flooded. Surface water temperatures cool rapidly, due to processes such as atmospheric cooling and radiational heat transfer.. The difference in temperature measured at location 36SW0302 (approximately 500 feet downstream of the treatment system discharge) and 36SW0010 (upstream of the treatment system discharge) ranged from -0.72 °C to 0.75 °C from November 2001 through March 2002. These data indicate the temperature of the discharged water equilibrated with the waters of the K2 west bog ditch within 500 feet of the point of discharge. Therefore, the temperature exceedances did not significantly impact the ecology of the K2 bog west ditch.

4.3.1.2 Dissolved Oxygen

DO concentrations in the surface water of the Quashnet River and bogs area were influenced by (1) ambient air temperature (DO concentrations are inversely related to temperature), (2) chemical and geochemical processes, (3) photosynthesis (oxygen-producing process), (4) respiration, and (5) agricultural activities (e.g., bog ditch maintenance). In general, surface water DO concentrations increase from mid-morning through late afternoon due to photosynthesis occurring in aquatic plants (e.g., algae and macrophytes), which produce more oxygen than can be consumed by COD or BOD. During the hours when there is not enough light to sustain photosynthesis, respiration

becomes the dominant process. When respiration and chemical oxidation are the dominant processes, oxygen is consumed at a rate greater than it is replaced from the atmosphere; this decreases the DO concentration of the surface water.

During the reporting period, the DO concentrations measured in the Quashnet River and bogs area ranged from 1.28 (measured on 29 August 2001 at 36SW4188) to 17.97 mg/L (measured on 10 August 2001 at 36SW0010) (Figure 4-16, Figure 4-18, Table 4-6).

The hourly DO concentrations measured at 36SW0300, immediately downstream of the treatment system surface water discharge, ranged from 6.57 to 16.89 mg/L during the reporting period (Figure 4-18). The DO concentrations measured at location 36SW0300 demonstrate that the treatment system surface water discharge meets the surface water discharge criteria (more than 5.0 mg/L in warm water fisheries according to 314 CMR 4.05).

During the reporting period, the DO concentration remained above 9.0 mg/L at location 36SW0221, the K1 bog sampling location most influenced by the groundwater infiltration trench (Figure 2-4, Figure 3-1, Table 4-6). Therefore, DO data indicate the discharge of treated water from the infiltration trench to the K1 bog did not adversely impact this ecosystem.

4.3.1.3 pH

The pH of the Quashnet River and bogs is influenced by (1) chemical, geochemical, and biological processes occurring in the surface water and sediment, (2) upwelling groundwater, (3) precipitation, and (4) agricultural activities (cranberry growing). During the reporting period, the pH of the Quashnet River and bogs surface water ranged from 5.58 (measured on 02 August 2001 at location 36SW0010) to 7.61 (measured on 31 May 2001 at location 36SW0032) (Table 4-6). The pH of the Quashnet River and bog ditches were similar during the reporting period, with the Quashnet River locations having the lowest mean pH of 6.60 and the K6 bog having the highest mean pH of 6.81 (Figure 3-1, Table 4-6).

During the reporting period, the difference in the pH measured at location 36SW0300 (downstream of the treatment system surface water discharge) and 36SW0010 (immediately upstream of the treatment system surface water discharge) ranged from -0.09 to 0.60. Of the 59 comparisons of pH measured at locations 36SW0300 and 36SW0010, five exceeded the criteria stated in 314 CMR 4.05 (the discharge to surface water shall not change the pH by more than 0.5 standard units). The difference in pH measured at location 36SW0302 (approximately 500 feet downstream of the treatment system discharge) and 36SW0010 (upstream of the treatment system discharge) ranged from -0.01 to 0.55 during the reporting period. These data indicate the pH of the discharged water equilibrated with the waters of the K2 west bog ditch within 500 feet of the point of discharge, with the exception of June and September 2001. Since the difference in the pH measured downstream of the treatment system discharge was less than or equal to 0.60 standard units and the Massachusetts criteria for pH was exceeded by a maximum of 0.10, the discharge of treated groundwater did not significantly impact the ecology of the K2 bog west ditch (AFCEE 2002c, 2000a).

4.3.1.4 Specific Conductance

Specific conductance is a measure of the ionic strength (i.e., an indirect measurement of salinity) of a water body. The specific conductance of the Quashnet river and bogs system is influenced by geochemical processes (e.g., dissolution of minerals), biological processes, atmospheric processes, and agricultural activities. During the reporting period, the specific conductance measured in the surface water of the Quashnet River and bogs ranged from 43 μS/cm (measured on 25 July 2001 at location 36SW0007) to 316 μS/cm (measured on 17 May 2001 at location 36SW0300) (Figure 3-1, Table 4-6). The range of specific conductance measured during the reporting period was within the normal range measured for surface water bodies on upper Cape Cod.

4.3.1.5 Oxidation-Reduction Potential

ORP indicates whether the aquatic environment is oxidizing or reducing. During the reporting period, the ORP measured in the Quashnet River and bogs ranged from -32 mV

(measured on 25 October 2001 at 36SW0036) to 500 mV (measured on 18 April 2002 at 36SW0010) (Figure 3-1, Table 4-6). The Quashnet River and bogs were generally an oxidizing environment since most of the surface water ORP measurements were greater than zero.

4.3.1.6 Turbidity

Biological processes, precipitation, and agricultural activities influence turbidity in the Quashnet River and bogs. During the reporting period, the turbidity measured in the surface water of the Quashnet River and bogs ranged from 0 to 67 NTU (Table 4-6).

4.3.2 Surface Water Ethylene Dibromide Results

Surface water samples from 14 locations in 2001 and 13 locations in 2002 were analyzed for EDB (Figure 3-1, Table 4-6). The town of Mashpee requested two Quashnet River samples be collected downstream of the bog complex (36SW0031 and 36SW0032) and analyzed for EDB. EDB was not detected in samples analyzed from these locations. EDB was not detected in surface water samples collected from the K1 or K2 bog ditches during the reporting period.

EDB continues to upwell in the southern and southeastern area of the K6 bog (36SW0019 and 36SW4188). The EDB concentrations measured in surface water samples collected from K6 bog locations ranged from 0.043 to 0.190 μg/L from 36SW4188 and 0.011 to 0.074 μg/L from 36SW0019 (Figure 3-1, Table 4-6). Low concentrations of EDB were detected sporadically in Quashnet River samples collected from 36SW0015, upstream of the developed Quashnet bogs (0.007J μg/L in December 2001) and 36SW0003, middle of the developed bogs (0.01J to 0.011 μg/L from October to December 2001).

Groundwater data and modeling indicate the source of intermittent detections of EDB in surface water samples collected from location 36SW0015 is most likely northwest of the FS-1 plume, in the vicinity of the Eastern Briarwood monitoring area (AFCEE 2001d). EDB was detected in surface water samples collected from 36SW0003 after the cranberry grower cleaned the bog ditches along the southern and eastern sides of the K4 bog

(Figure 3-1). Prior to the removal of accumulated sediment and other debris (e.g., leaf litter) from the K4 bog ditch, the upwelling groundwater flowed west and north. The water in the K4 bog ditch discharged to the Quashnet River near location 36SW0015. After the sediment and other debris had been removed from the K4 bog ditches, the surface water flow direction changed from primarily west to east. The latter surface water flow discharged to the Quashnet River upstream of location 36SW0003. The EDB concentrations detected in the surface water of the Quashnet River and bogs were below human health and ecological risk benchmarks (see Section 4.5).

4.4 REMEDIAL SYSTEM RESULTS AND DISCUSSION

During the reporting period, the FS-1 remedial system processed 384 million gallons of contaminated water removing 0.99 kg (2.2 lbs) of EDB. The groundwater treatment system was monitored for selected chemical, physicochemical, and general plant operational parameters. Treatment plant analytical results are presented in Table 4-7 and Table 4-8.

4.4.1 Process Water Chemistry

During the reporting period the EDB concentrations of the deep extraction well (36EW0005) ranged from 1.12 to 1.85 μg/L and the shallow extraction wellpoints (36PLT01005) ranged from 0.11 to 0.29 μg/L (Figure 4-19, Table 4-7). The detections of EDB in the lead GAC unit precipitated four carbon exchanges during the reporting period, 16 May 2001, 21 August 2001, 19 November 2001, and 26 February 2002.

4.4.2 Process Water Physicochemistry

The physicochemical data collected from the treatment plant influent and effluent during the reporting period are presented in Table 4-7 and Table 4-8.

The mean temperature of the treatment plant effluent was 10.60 °C during the reporting period. The temperature difference between the combined influent (36PLT01001) and the effluent (36PLT01003) of the treatment system ranged from 0.02 to 0.37 °C during

the reporting period (Table 4-7). The treatment system effluent met the temperature criteria in the Mashpee Conservation Commission Amended Order of Conditions (i.e., the difference between the treatment plant influent and effluent must be less than 2 °C) (MCC 2002).

The DO concentration as measured at the treatment system effluent sampling port ranged from 6.04 to 9.79 mg/L (mean effluent DO concentration of 7.32 mg/L). Eighteen of 23 biweekly DO concentration measurements of the treatment system effluent failed to meet the Mashpee Conservation Commission requirement that the DO concentration of the treatment system effluent discharged to groundwater remain above 8 mg/L (MCC 1999). The DO concentrations measured at 36SW0221 (the location most influenced by the infiltration trench in the K1 bog) remained above 8 mg/L during the reporting period (Table 4-6). The Commonwealth does not consider aquatic biota to be in stressed conditions if the DO concentration of surface water remains equal to or above 5 mg/L. Therefore, the discharge of the infiltration trench did not significantly impact the ecology of the K1 bog north ditch. The 8 mg/L guideline was removed in the Amended Order of Conditions (MCC 2000).

The pH of the treatment system effluent ranged from 5.79 to 6.44 during the reporting period (Table 4-7). The difference between the monthly mean pH measured from the surface water of the K1 bog and the treatment system effluent ranged from -0.09 to 0.71 standard units. The difference of the pH of the treatment system effluent and the surface waters of the K1 bog exceeded the criteria for pH stated in 314 CMR 4.05 (the discharge to surface water shall not change the pH by more than 0.5 standard units) during December 2001 and February 2002. The pH of the K1 bog ranged from 5.58 to 7.31 during the reporting period. Since the pH of the K1 bog had a greater range than the treatment system effluent, the discharge from the infiltration trench did not significantly impact the ecology of the K1 bog north ditch.

The specific conductance of the treatment system combined influent ranged from 75 to 90 µS/cm (mean 79 ± 3.4) and the effluent ranged from 76 to 90 µS/cm (mean 79 ± 3.3)

(Table 4-7). These data indicate the treatment process did not change the ionic strength of the groundwater.

The ORP of the treatment system combined influent ranged from 206 to 437 mV (mean 286 ± 62) and the effluent ranged from 180 to 418 mV (mean 258 ± 64) (Table 4-7). These data indicate the treatment process did not change the ORP of the groundwater.

The turbidity of the treatment system combined influent ranged from 0 to 4 NTU (mean 0.32 ± 1.14) and the effluent ranged from 0 to 0.3 NTU (mean 0.02 ± 0.11) (Table 4-7). These data indicate the treatment process did not add particulates to the effluent.

Table 4-8 presents the physicochemical analytical results from the combine influent and effluent. These analytes or measurements were either nondetect or detected at low levels. There was very little difference between the results of from the combined influent and the effluent samples.

4.4.3 System Flow Rates and Downtime

The Quashnet treatment system operated 99 percent of the time from May 2001 through April 2002 (Table 4-9). The carbon beds in the treatment system were replaced four times during the reporting period, in May, August, and November 2001, and February 2002.

4.4.4 Shallow Extraction Wellpoints

Based on the recommendations presented in the 2001 annual report (AFCEE 2002c), the SWP extraction system was reconfigured during January 2002 as follows (Figure 2-1 and Figure 2-4):

Shallow Extraction Well Groups	Number of Wellpoints Operating May – December 2001	Number of Wellpoints Operating January – April 2002
Adjacent to K2 bog	72 of 132 ON	83 of 132 ON

Adjacent to northern side of K6 bog	23 of 23 ON	0 of 23 ON
Adjacent to western side of K6 bog	0 of 20 ON	20 of 20 ON

4.4.5 Treatment Volume and Mass Removal

The volume of water treated by the FS-1 treatment system and the estimated mass of EDB removed from the FS-1 plume are summarized below.

Date Range	Total Volume Extracted	Total EDB Removed	Volume Extracted at EW5	EDB Removed at EW5	Volume Extracted at SWP	EDB Removed at SWP
May 2001 – April 2002	384 million gallons	0.99 kg (2.2 lbs)	156 million gallons	0.83 kg (1.8 lbs)	228 million gallons	0.16 kg (0.35 lbs)
April 1999 - April 2002	1.05 billion gallons	4.35 kg (9.6 lbs)	377 million gallons	2.76 kg (6.1 lbs)	686 million gallons	1.59 kg (3.5 lbs)

System performance modeling was conducted using the 2001 FS-1 groundwater model to predict the mass of EDB removed by the current treatment system (AFCEE 2001a). The current plume shell developed in support of the FS-1 remedial system design represents conditions in October 2000 (AFCEE 2001a). The simulation was conducted from October 2000 to April 2002.

EDB concentrations at the deep extraction well (36EW0005) and the shallow extraction wellpoints were calculated based on the simulated transport of the October 2000 plume shell and pumping rates for each month of the modeling period (October 2000 to April 2002). Figure 4-19 shows the model-predicted EDB concentrations at the deep extraction well and SWP extraction system. Measured influent EDB concentrations from the treatment system are also plotted in Figure 4-19. Model-predicted concentrations are similar to measured concentrations, suggesting that the 2001 FS-1 model adequately simulates the groundwater flow system and the operation of the remedial system.

The model predicted that the shallow extraction wellpoints would remove 0.31 kg of EDB and extraction well 36EW0005 would extract 1.6 kg of EDB from May 2001 to April 2002. The actual mass of EDB removed by the shallow extraction wellpoints and the extraction well during this time period was 0.16 kg and 0.83 kg, respectively. The total mass of EDB contained in the FS-1 plume, as of October 2000, was estimated to be 8.1 kg (AFCEE 2001a). The remedial system removed approximately 1.6 kg of EDB between October 2000 and April 2002. Thus, the current remedial system removed approximately 20 percent of the total estimated contaminant mass (as of October 2000) between October 2000 and April 2002. The deep extraction well and the SWP extraction system removed about 80 percent and 20 percent, respectively, of the extracted EDB mass.

The total mass of EDB removed by the treatment system was 0.99 kg, for the period of May 2001 to April 2002, which was lower than the model-predicted mass of 1.91 kg. The model overestimated the influent concentrations of the remedial system by approximately 52 percent. This was caused by the conservative nature of the FS-1 model, since the model does not include an EDB degradation term in its simulation and probably overestimated the initial (starting) EDB plume shell. However, considering the complex nature of the flow system and EDB plume distribution pattern, the comparison shows that the 2001 FS-1 flow and transport model is a reasonable tool to predict future system performance. The model will be recalibrated using data collected during the expanded system startup pumping test planned for fall 2003.

4.5 RISK MANAGEMENT RESULTS

A preliminary screening-level risk evaluation was performed on the monitoring data to determine whether chemicals were present in concentrations that may be harmful to human or ecological receptors. This evaluation included assessment of groundwater, surface water, and the treatment plant effluent.

4.5.1 Groundwater

Groundwater EDB concentrations were compared to the MMCL of 0.02 µg/L (DEP 1998). During the reporting period, groundwater EDB concentrations ranged from less than the method detection limit of 0.005 to 21.30 µg/L (36MW1038B, January 2002). EDB was detected at a concentration equal to or above the MMCL in groundwater samples from 29 of 69 monitoring wells or piezometers and 21 of 30 shallow extraction wells (Figure 3-3, Table 4-4).

FS-1 plume source area wells (36MW0002, 36MW0007, 36MW0010A, and 36MW0015) were monitored for VOCs and metals (Figure 3-3, Table 4-5). Five VOCs were detected in groundwater samples, chloroform (0.36J to 2.78 µg/L), ethylbenzene (69 to 152 µg/L), toluene (1.8 to 141 µg/L), and meta- plus para-xylene (126 to 594 µg/L), and ortho-xylene (52.8 to 149 µg/L). All concentrations of VOCs were below their respective MMCL (Table 4-5).

Thirteen metals were detected in groundwater samples collected from the FS-1 plume source area wells; none of the metals were detected at concentrations above their respective MCL (Table 4-5). Lead, however, exceeded the EPA and DEP action level of 15 µg/L for both sampling events at source area monitoring wells 36MW0002 and 36MW0007. Natural attenuation will remove lead from groundwater as background geochemical conditions reassert themselves, leading to the formation of insoluble lead carbonate, coprecipitation with or adsorption on iron-manganese oxyhydroxides, or adsorption by organic matter.

4.5.2 Surface Water and Remedial System Effluent

In the evaluation of ecological risk, maximum detected concentrations of analytes were compared to U.S. Environmental Protection Agency (EPA) surface water benchmarks obtained from Ecotox Thresholds (EPA 1996). EDB concentrations detected in surface water were compared to the ecological benchmark derived for AFCEE by Oak Ridge National Laboratory (AFCEE 1998). For human health, maximum detected

concentrations were screened against hazard- and risk-based concentrations developed for surface water. The screening-level human health risk evaluation assesses imminent risk, which is an excess individual cancer risk of 1 x 10^{-3} for carcinogenic compounds and a hazard quotient of 10 for noncarcinogenic compounds.

During the reporting period, EDB concentrations measured in surface water were below the risk-based concentration (6.5 μg/L) (Appendix C) and the ecological benchmark (31 μg/L) (Table 4-6) (EPA 1996; AFCEE 1998).

5.0 CONCLUSIONS AND RECOMMENDATIONS

Recommendations to modify the monitoring program presented in the 2001 annual report were instituted in January 2002 for groundwater and surface water monitoring (AFCEE 2002c). There are no recommendations for future modifications of the monitoring program.

5.1 GROUNDWATER AND SURFACE WATER HYDROLOGY

Analysis on the surface water flow rate and groundwater discharge calculation indicate that the Quashnet bogs remain an area of significant groundwater discharge as concluded by prior monitoring data. The calculated groundwater discharge rates to the bogs were between 2.25 and 3.03 cfs in the reporting period. Groundwater contours constructed from groundwater level data also indicate that the Quashnet bogs are the groundwater discharge locations.. Calculated vertical gradients reveal the positive effects of the deep extraction well (36EW0005) and the SWP extraction system on groundwater flow, with upward or downward flow toward the deep extraction well and upward flow toward the shallow extraction wellpoints. Vertical gradient analysis also indicates that flooding the bogs reduces the discharge of groundwater to the bogs.

5.2 GROUNDWATER CHEMISTRY

Groundwater EDB concentrations have generally declined throughout the FS-1 plume, with the maximum concentration down from 29 µg/L in 2000 to 17.7 µg/L in March 2002. The overall plume geometry, as defined by exceedances of the MMCL of 0.02 µg/L, remains essentially unchanged, extending approximately 6525 feet from just north of 36MW0603A to the K6 bog adjacent to the Quashnet River. The core of the plume continues to be defined by 36MW1038B, which is located approximately 900 feet upgradient of the deep extraction well (36EW0005). Subsurface EDB contamination has been detected only as far south as the northern edge of the K6 bog, although EDB continues to be detected in surface water samples from the southern part of that bog. Elsewhere, EDB upwelling appears to be confined to the SWP system along the ditch east of the K2 bog and the ditch between the K2 and K6 bogs. Plume dynamics beneath

the K1 and K2 bogs are complex, with concentrations in three wells increasing markedly towards the end of the current reporting period. Increases in two of the wells appear to reflect incomplete capture of the plume by 36EW0005. This extraction well is known to permit the eastern portion to escape downgradient to be captured by the more southerly SWP system, a problem that would be largely mitigated with the installation and activation of EW-7 and EW-1 as part of the expanded FS-1 remedial system. Increases in the third well, farther downgradient, are attributed to small-scale heterogeneity in the plume.

Monitoring of the FS-1 source area identified five compounds and one metal associated with petroleum products (ethylbenzene, toluene, o- and m- and p-xylene) and lead. For the VOCs, the low concentrations and declining trends indicate that there is no continuing source for the FS-1 plume and that natural attenuation will soon remove these compounds entirely. Lead will also be removed from the groundwater by precipitation or adsorption as the geochemical environment reverts to oxidizing (background) conditions. These compounds are absent in the monitoring well immediately downgradient of the source area, indicating that they are attenuating in place.

The existing monitoring network and sampling frequency are adequate to monitor the FS-1 plume while only the current remedial system (36EW0005 and the shallow wellpoints) is in operation. AFCEE does not propose any changes in sampling based on the findings during the current reporting period.

5.3 SURFACE WATER CHEMISTRY

The surface water of the K1 and K2 bogs were EDB-free during the reporting period. EDB continues to upwell in the K6 bog. EDB was detected intermittently in samples from the Quashnet River (36SW0015). The source is mostly northwest of the FS-1 plume in the vicinity of the Eastern Briarwood monitoring area.

The discharge of treated groundwater has improved the water quality of the K2 bog west ditch by increasing flow, DO through aeration, and moderating temperature shifts. There

were no significant ecological impacts associated with the operation of the FS-1 remedial system.

5.4 REMEDIAL SYSTEM

The Quashnet River and bogs treatment system operated 99 percent of the time from May 2001 through April 2002. The treatment system has been successful in intercepting EDB-contaminated groundwater before it enters the K1 and K2 bog ditches and the Quashnet River. During the reporting period, the treatment system has processed 384 million gallons of contaminated groundwater, removing 0.99 kg (2.2 lbs) of EDB. Since April 1999, the treatment system has processed 1.05 billion gallons of contaminated groundwater and removed 4.35 kg (9.6 lbs) of EDB. EDB continues to upwell in the K6 bog. However, the concentrations of EDB in the surface water of the K6 bog were below screening-level human health and ecological benchmarks.

The shallow wellpoint data show that the highest EDB concentrations now occur in the southwest branch of the SWP system between the K2 and K6 bogs, with the maximum detection of 1.09 µg/L. Overall, concentrations in this branch have increased during the reporting period. The highest concentrations during previous reporting periods were in the midsection of the northern branch adjacent to the K2 bog, where the maximum detection is now 0.458 µg/L and concentrations have generally decreased. The eastern branch of the SWP extraction system, along the northern edge of the K6 bog, contains no detections of EDB.

The FS-1 model-predicted mass capture by the current treatment system is similar to the observed mass capture, suggesting that the 2001 FS-1 model adequately simulates the groundwater flow system and the operation of the remedial system. The comparison demonstrates that the 2001 FS-1 model can be used to predict the future system performance.

5.5 RISK MANAGEMENT

A requirement of the ecological impact assessment included a preliminary screening-level risk evaluation to determine whether chemicals detected in groundwater, surface water, or the treatment system effluent were present in concentrations that may be harmful to human or ecological receptors. Groundwater data were compared to MMCLs (DEP 1998). Surface water and treatment system effluent data were compared to ecological benchmarks (AFCEE 1998; EPA 1996) and risk- and hazard-based concentrations calculated from current EPA toxicity data (AFCEE 2002c). EDB concentrations measured in surface water samples collected during the reporting period were below the risk-based concentration (6.5 μg/L), the hazard-based concentration (61 μg/L), and the ecological benchmark (31 μg/L) (AFCEE 2002c, 1998).

5.6 RECOMMENDATIONS

On 13 October 2002, the FS-1 treatment plant was destroyed by a fire. The FS-1 treatment system has been inoperative since that time. A focused monitoring effort was approved, was implemented beginning October 2002, and will continue until a new plant is operational. Details of the current monitoring of the FS-1 plume are presented in project note ENR-J23-35Z15616-P1-0004, Changes to the FS-1 SPEIM Program, dated 31 January 2003.

Once the FS-1 treatment system is operational, AFCEE recommends reducing the monitoring frequency of wells for EDB in groundwater in the northern portion of the plume and in wells outside the plume boundary from quarterly to semiannually (Table 5-1). Monitoring frequency of wells and piezometers not listed in Table 5-1 will not change. The appropriateness of the current monitoring program will be evaluated after the hydraulic evaluation of the expanded remedial system is performed.

6.0 REFERENCES

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